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SOLAR STILL EFFICIENCY AUGMENTATION USING CYLINDRICAL SWEEPING AGITATOR ON THE ABSORBER PLATE

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ABSTRACT

Passive solar stills are simple devices which generate potable water by way of desalination of brackish water. However, the main limitation of this device is its poor still efficiency. This paper presents an innovative technique of increasing the still efficiency using the sweeping agitator system in the passive solar still device. The agitator rotates on the still basin plate thereby sweeping the water on the plate and enhances mixing which results in increased heat transfer. The experiment is carried out on a single slope passive solar still in the outdoor conditions of Dubai during the month of May. The presence of sweeping agitator is shown to be effective in enhancing the distillate output as well as solar still efficiency. The results show that the solar still efficiency increased by about 3.95% as compared to base still.

KEYWORDS: Solar Still, Still Efficiency, Desalination & Passive Solar Still

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Original Article

1. INTRODUCTION

Water scarcity is among the most dangerous crises in the world that currently affects half a billion people. A huge majority of those afflicted with such water shortages reside in arid and semi-arid regions. Desalination through Solar stills can be a simple and economically viable solution to this problem. A solar still is a very simple and cost-effective solution to address global water shortages. Solar stills are small and very simple in construction and hence require minimal maintenance and are easily transportable. Solar distillation is a tried and true technology. The first documented proof of a solar still was by Arab alchemists back in the 16th century. The core principle behind any conventional Solar Still is the greenhouse effect, through which heat from the Sun’s radiation enters the glass setup and stays trapped inside the still, thus allowing a high temperature to be attained inside the Still. The sun's energy heats water to the point of evaporation. As the water evaporates, water vapour rises, condensing on the glass surface for collection onto the guide ways. This process removes any heavy metals and microorganisms and the collected output is of the highest quality. The distilled water obtained through the use of a solar still has a better taste relative to water from a commercially distilled source. Solar stills essentially just operate on the processes of evaporation and condensation, and are thus very pure. Solar stills can therefore be very useful in providing water for any cooking and drinking needs. However, the biggest limitation of a solar still is its lower distillate output leading to lower still efficiency. Hence, there is a need to improve the distillate output and hence the solar still efficiency which could make the solar still more capable of producing drinking water. Several techniques have been proposed in the past by various researchers in this regard. Sellami et al (2017) have shown that the distillate output can be significantly improved to an extent of 58% by using blackened sponge on the absorber plate. The sponge absorbs the solar heat and acts as heat storage device which augments the evaporation rate. Basin water depth has been shown to affect the performance of still by Suneja and Tiwari (1999) where

increasing water depth drastically reduces the output of still. Inclination of glass cover also have been shown to influence the still performance. Various angle of inclination such as 15^o,35^o, 45^o and 55^o have been tested by Bilal et al (2000) and found that the best angle of inclination is about 35^o. It has been also shown by Ghassan et al (2013) that the better inclination is the latitude angle ± 10^o. Minasian and Karaghouli (2013) have shown that the use of jute cotton which serve as wick materials increase the distillate output by about 85% due to increased evaporation rate. The productivity has also been improved by using granite gravel which provide wick action by Hitesh (2012). Omara and Kabeel (2014) have reported an increase of about 42% in productivity sand beds as energy storage materials. An efficiency of 85% has been reported by El-sebaii et al (2009) by using stearic acid as heat storage material. Use of fins enhances the heat transfer area on the basin plate and could improve the productivity by 45% as reported by Velmurugan et al (2009). The performance can also be increased by using reflectors inside the basin which reflect the radiation onto the plate. An additional use of sun tracking mechanism would provide further enhancement as suggested by Abdallah et al (2008) while an enhancement of about 48% is reported by the use of both internal and external reflectors by Tanaka Hiroshi (2006). Thus various efforts have been made in passive as well as active solar still where the influence of glass cover, energy storage materials, wick materials fins multi-slope still arrangement on the still efficiency have been reported. However, the use of sweeping agitators on the basin plate to provide fluid mixing is not reported in the literature to the best of the knowledge of the authors. In this regard, an experimental analysis has been carried out to evaluate the influence of sweeping agitator on the distillate output and still efficiency of passive still system.

It is a known fact that the turbulence in a fluid leads to increased energy exchange owing to improved fluid mixing. This paper makes use of cylindrical sweeping agitator to create agitation in the water stored on the absorber plate in the still basin. It is found from the literature that there has been no such study reported in the past. Hence, the objective of this paper is to experimentally evaluate the effect of sweeping cylindrical agitators on the solar still distillate productivity as well as still efficiency.

2. EXPERIMENTAL ANALYSIS

2.1 Experimental Set Up

The cross-sectional view of the baseline solar still is shown in Figure 1. The solar still is constructed out of plywood of 10 cm thickness which is insulated from outside using thermocol sheets. The solar still has double slope on the glass cover which are inclined at an angle of 30^o to the horizontal. The absorber plate is of GI sheet material of 0.9 mm thick and is painted black on its surface. The thickness of glass cover is 0.2 cm. The solar still basin has square shape with a side of 60 cm and the height of basin is kept at 10 cm. Figure 2 shows the pictorial view of the baseline solar still. Figure 3 shows the pictorial view of the arrangement of sweeping cylindrical agitator on the absorber plate. The sweeping cylinder is made of GI pipe and is painted black on its surface to achieve solar heat absorption as shown in Figure 4. The cylinders are rotated at low speeds by a motor placed at the bottom of the absorber plate.

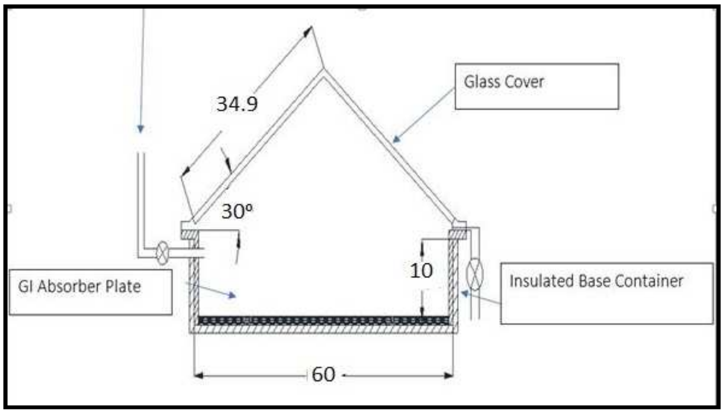

Figure 1: Construction Details of Base Solar Still (All Dimensions in cm)

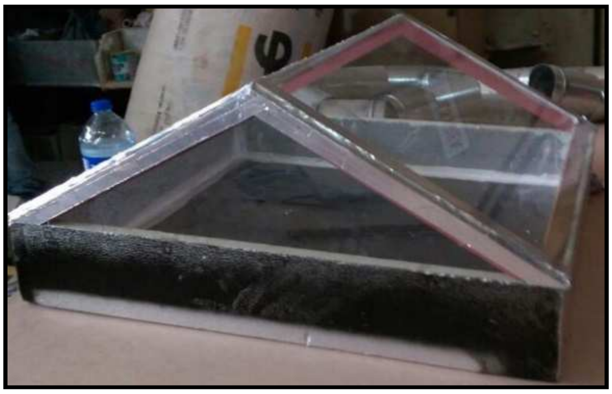

Figure 2: Pictorial view of Baseline Solar Still

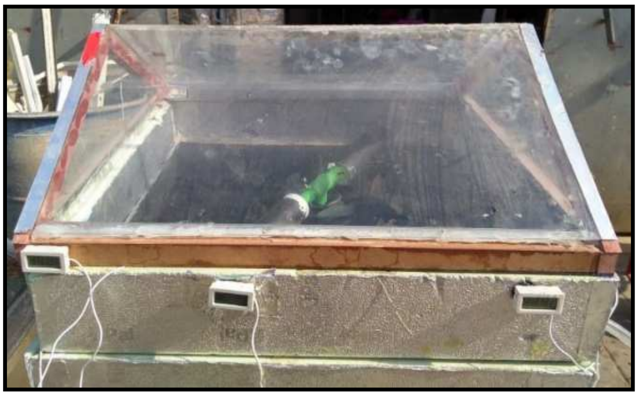

Figure 3: Pictorial view of Solar Still with Agitator

Figure 4: Close up View of Cylindrical Sweeping Agitator

2.2 Experimental Procedure

The solar still with and without agitator was installed in the outdoor environment and the testing was carried out simultaneously in order to evaluate their relative performance. Both the basins were filled with water to a height of 1 cm and provisions were made to send in more water periodically as the water dries out in the basin. The temperature of glass cover, absorber plate, inside air and water were measured using thermocouples. The basins are insulated well enough to prevent heat loss by conduction using thermocol insulation. The condensed water was collected in a jar and the quantity was noted. The experiment was repeated on four consecutive days to check the results for repeatability.

2.3 Data Reduction

The experimental measurements made with respect to the glass temperature, basin water temperature and absorber temperature are used for calculating the performance parameters of solar still using the following equations [11]:

$$P_w = e^{\left(25.317 - \frac{5144}{T_w + 273}\right)} \tag{1}$$

$$P_g = e^{\left(25.317 - \frac{5144}{T_g + 273}\right)} \tag{2}$$

$$h_{cw} = 0.884 \times \left[T_w - T_g + \frac{(P_w - P_g)(T_w - T_g)}{268.9 \times 10^3 - P_w}\right]^{1/3} \tag{3}$$

$$h_{ew} = 16.273 \times 10^{-3} \times h_{cw} \times \left(\frac{P_w - P_g}{T_w - T_g}\right) \tag{4}$$

$$q_{ew} = h_{ew} \times (T_w - T_g) \tag{5}$$

$$\eta = \frac{q_{ew}}{I(t)} \tag{6}$$

3. RESULTS AND DISCUSSIONS

The experiment was carried out on four consecutive days from 10:00 h to 15:00 h at Dubai location. The measurements of the temperature of basin water, glass and absorber temperature were found to vary with the time of the day as shown in Figure 5 for base solar still. It is seen that the absorber plate temperature (GI sheet) is higher is higher as compared to water and glass cover temperature. This is due to the fact that the absorber plate receives and absorbs the solar radiation energy as it is coated in black which has higher radiation absorptivity. The water stored on the GI absorber sheet gets heated up and is found to be closer to the plate temperature throughout the experiment. Since, the water receives heat from the plate, its temperature is generally lower than the plate temperature as is clearly shown in Figure 5. The glass temperature is lower than plate temperature as it is exposed to atmospheric air which creates a cooling effect on glass cover. The glass cover provides the cooling surface for evaporated water to condense on its surface as it is relatively cooler than the absorber plate. The condensed water is collected as distillate output continuously in a separate collection bottle. The measurements of the temperature of basin water, glass and absorber temperature for enhanced model in the presence of sweeping agitator are shown in Figure 6. The trends of temperature variation are seen to be similar to the base solar still. However, the temperature levels of water, plate and glass cover are different in the presence of agitator.

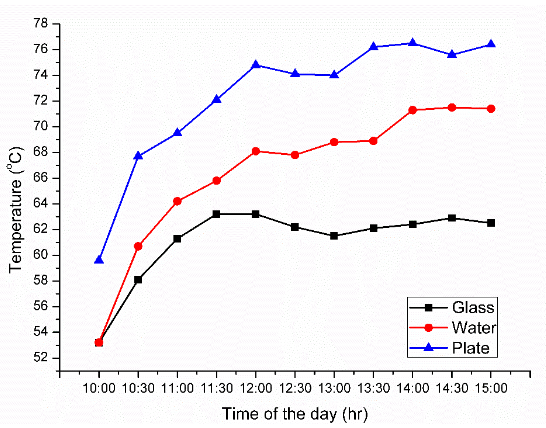

Figure 5: Temperature Behaviour with Time for Base Solar Still

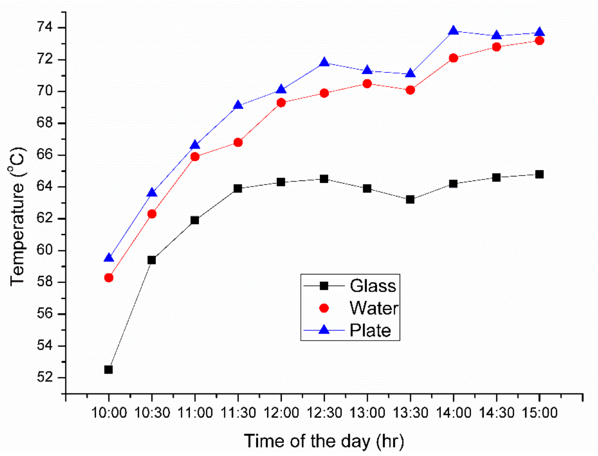

Figure 6: Temperature Behaviour with Time for Solar Still Fitted with Sweeping Agitator

The temperature of water is found to be much closer to the plate temperature in the presence of agitator system as seen in Figure 6. This can be due to the vigorous mixing effect the agitator creates thereby bringing in the surface colder water in contact with the hot plate surface thereby increasing the average temperature of water stored on the plate. In the case of base still, the mixing effect is absent and the heating process is predominantly through natural convection heat transfer within the water. As a result, the water will be at a relatively lower temperature over the plate as compared to the enhanced model which uses agitator system.

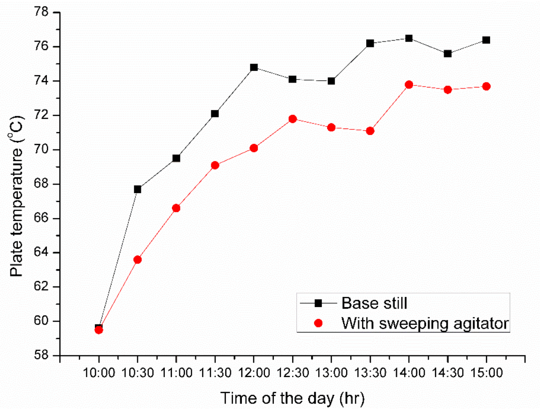

Figure 7: Comparison of Plate Temperature for Base Still and the Still Fitted with Sweeping Agitator

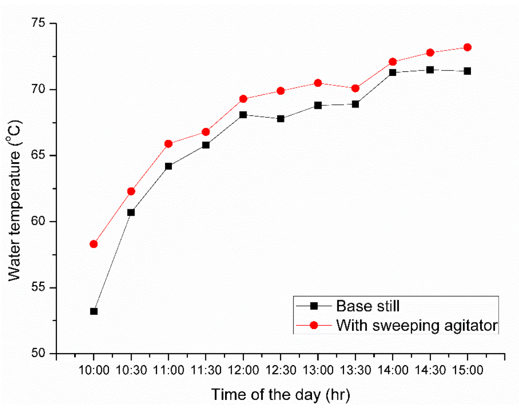

Figure 8: Comparison of Basin Water Temperature for Base Still and the Still Fitted with Sweeping Agitator

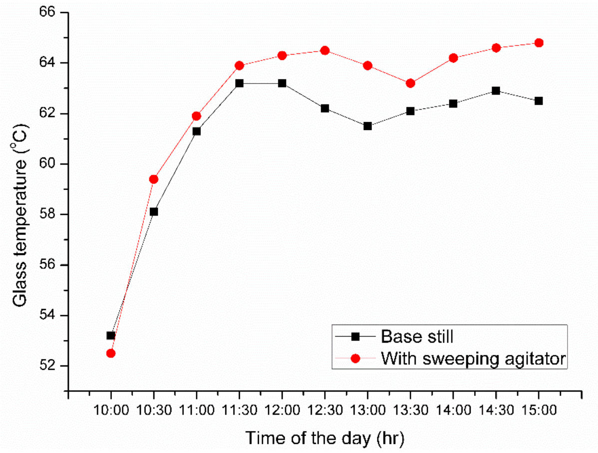

Figure 9: Comparison of Glass Cover Temperature for Base Still and the Still Fitted with Sweeping Agitator

Figure 7 shows that the temperature of the plate is relatively lower for enhanced model as compared to base still. This is due to the fact that the presence of sweeping agitator creates vigorous mixing in the water stored on the plate thereby increasing the heat transfer rate from the plate. The sweeping effect of water causes the water to mix well which helps in transferring the relatively colder water at the top closer to the hot plate. As a result, the water temperature will be higher for enhanced model while the plate temperature will be lower as compared to base solar still as shown in Figure 8. This leads to increased evaporation rate of water which condenses on the glass cover giving off the latent heat thereby heating up the glass cover slightly. Since, the evaporation rate is higher in the presence of agitator system, more vapours condense at the glass cover by rejecting more heat thereby slightly raising the glass temperature as shown in Figure 9.

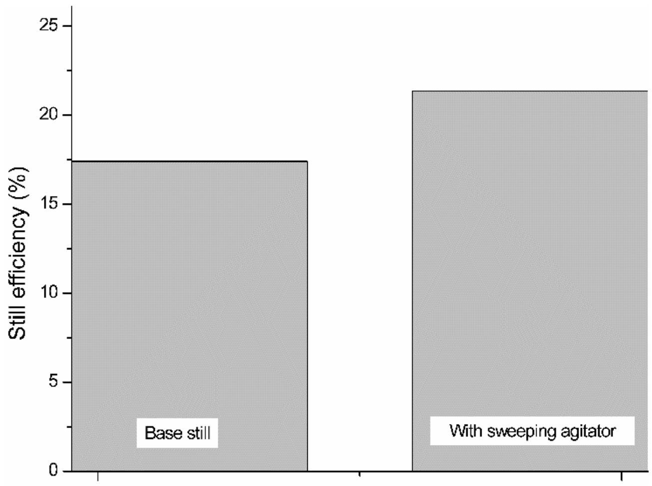

Figure 10: Comparison of Solar Still Efficiency for Base Still and the Still Fitted with Sweeping Agitator

Figure 10 shows the comparison of solar still efficiency for solar still with and without sweeping agitator. The presence of agitator is clearly seen to improve the still efficiency to a considerable extent. As the agitator starts rotating, it sweeps the water on the plate surface thereby vigorously mixing thereby agitating the water leading to increased heat energy exchange within the water volume. This agitation effect is a volumetric effect wherein the entire water volume undergoes mixing leading to increased evaporation rate leading to increased still efficiency as shown in Figure 11. The average increase in still efficiency in the presence of sweeping agitator is about 3.95% as compared to base still.

4. CONCLUSIONS

The present work evaluated the effect of sweeping agitator on the productivity of solar still. The major conclusions of the present work are as follows:

- The presence of sweeping agitator increases the evaporation rate of water leading to increased distillate output.
- The average still efficiency for base still is about 17.4% while it is about 21.35% for the still fitted with sweeping agitator.
- The average increase in still efficiency in the presence of sweeping agitator is about 3.95% as compared to base still.

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NOMENCLATURE

h_{ew}	Evaporative heat transfer coefficient (W/m^{2}K)
h_{cw}	Convective heat transfer coefficient (W/m^{2}K)
T_w	Water temperature (K)
T_g	Glass temperature (K)
P_g	Partial saturated vapor pressure at glass temperature (N/m^2)
P_w	Partial saturated vapor pressure at water temperature (N/m^2)
q_{ew}	Rate of evaporative heat transfer (W/m^2)
$I(t)$	Solar radiation on the horizontal surface (W/m^2)=1100 W/m^2
η	Efficiency of solar still (%)